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Adoption of Building Information Modelling in Small and Medium-Sized Enterprises in Developing Countries: A System Dynamics Approach.

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Abstract

Despite the benefits reaped from the adoption of BIM (Building Information Modelling) in the construction industry, the adoption in developing countries where there is a lack of client and government support and directions is still facing many challenges. These challenges are compounded for SMEs (Small and Medium-sized Enterprises) which are the backbone of the industry because of scarce resources and the organizational structure. Extant research studies on BIM adoption have focused on large firms and a few research studies on SMEs were carried out in developed countries with a high level of awareness as compared to developing countries. This research study presents a desktop review of literature on BIM perceived barriers, challenges and benefits with respect to developing countries. The identified barriers were then grouped into a perspective (organisation/project level and industry level) and context (technology-related, economic-related and process/people-related) matrix. A conceptual causal loop diagram was developed based on the desktop review to investigate the adoption of BIM in SMEs using System Dynamics (SD) which enables complex system behaviours to be studied. The causal loop diagram illustrates the key variables and their interrelationships affecting the BIM adoption to enable better BIM adoption policies in SMEs. The findings revealed that process and people related barriers are the major challenges of BIM adoption in SMEs, and there are few studies conducted on BIM benefits in developing countries because there are still bottlenecks with adoption. Also, the clients are regarded as one of the major drivers of BIM adoption at the organisation/project level while the government is one of the major advocators at the industry level. Adoption of BIM is a necessity for the SMEs towards the goal of achieving a smart construction industry, as they represent the backbone of economies.

Keywords: Building Information Modelling (BIM), Small and Medium-Sized Enterprises (SMEs), Adoption, Challenges, Benefits, Developing Countries

1. Introduction

Towards the goal of achieving a smart industry and integration in the fragmented construction industry (Egan, 1998), there has been emerging various technologies and paradigms. Building Information Modelling (BIM) is an emerging process that has been changing the way the Architecture, Engineering and Construction (AEC) firms function since its inception about two decades ago (Arayici, 2011). BIM is viewed as a technology that constructs digitally one or more accurate virtual models of a building to support design through its phases, allowing better analyses and control than the manual process. In essence, BIM is a process of using technology as it consists of 10% technology and 90% process and people (Munir and Jeffrey, 2013). Extant research studies have assessed the perceived benefits and challenges of BIM in the construction industry. The benefits include effective delivery process, buildable project design, controlled whole life cycle cost, better production quality, automated assembly, better customer service, more life cycle data collected, reduction of errors, reduction of rework and waste, improved risk management, removal of waste from the construction process, and improved lean construction and design, among other benefits.

The adoption rate of BIM is not rapid, and so many countries and firms are still struggling with its adoption. The adoption rate of developed countries is faster than that of developing countries (Jung and Lee, 2015). Notably, the taxonomy of developing/developed countries adopted in this study is based on the United Nations Development Programme's (UNDP) Country Classification System (Gbadamosi, 2018). In surveys by McGraw Hill (Construction, 2015), there has been an increase in BIM adoption in the United Kingdom, France and Germany, and North America. Similarly, the National BIM report (NBS, 2017) has advocated that the adoption of BIM in the United Kingdom has increased from 13% in 2011 to 60% in 2017. BIM adoption in developed countries such as the United Kingdom, United States, Hong Kong, China, Australia, Norway, Finland, Denmark, and Malaysia enjoys strong government support (Wong et al. 2011); but this is not the case in developing countries such as Nigeria and Ghana where there is often a lack of government support and guidance for technologies such as BIM (Abubakar et al., 2014)

The construction industry in developing countries consists of more than 90% of small and medium-sized enterprises (SMEs) same as the developed countries (Love and Irani, 2004; Rodgers et al., 2015), and it has been perceived to be the backbone of economic growth. The organizational structure of the small firms makes changes easier when compared to that of large firms; the projects executed are smaller in scale which will make innovations easier and these projects can often achieve faster time benefits more than large scale projects (Arayici et al., 2011). The capabilities and characteristics of SMEs differ entirely from that of large firms which have been the primary focus of extant research studies on BIM adoption (Aranda-Mena et al., 2008; Ghaffarianhoseini et al., 2016; Hosseini et al., 2016; Hosseini et al., 2018c). A small number of employees, small scale projects executed, low annual turnover, scarce resources, and low IT knowledge transfer (Harris et al., 2013) characterize the SMEs, as compared to large firms. These characteristics have been regarded to be able to aid/hinder the BIM adoption in SMEs with benefits/challenges.

This research study focuses on identifying the critical variables and their interrelationships in relation to the BIM adoption in SMEs of selected developing countries based on existing literatures. This study is timely and indispensable because BIM is creating a gap 'digital divide' (Ayinla and Adamu, 2018) between SMEs and large firms in the routinely fragmented construction industry. Thus, more large firms are "BIM compliant" while more SMEs are "BIM complaint". Also, a dearth of study on BIM in SMEs (Hosseini et al., 2016; Hosseini et al., 2018c) has discovered no standard framework to help SMEs with BIM adoption (Lam et al., 2015). Similarly, this study is of importance as BIM in SMEs which are the backbone of economies is vital for integration of the construction industry and the SME roles are more crucial in developing countries (United Nations, 2001). Identifying both of the barriers and benefits of BIM adoption is essential, as these barriers must be checked for effective implementation (Olugboyega, 2018). Also, the adoption of BIM is a complex decision as it is affected by many interrelated factors. Thus, the present study is a desktop review of BIM literature from developing countries and the barriers/benefits were grouped into a perspective (industry level and organization/project level) and context (technology-related, economic-related and process/people-related) matrix. A conceptual causal loop diagrams were then adopted to map out the interrelationships between the identified critical factors. These diagrams can be used by the SME construction companies so as to boost the adoption rate of BIM.

The paper is structured into five sections: the first section provides an overview of BIM adoption, the second part highlights some previous research studies on BIM in SMEs, third part explains the research methodology adopted, the fourth part summarizes the key results of desktop literature review, and portrays the causal loop modelling, and the last part is the conclusions.

2. Literature Review

Survey methodology was adopted by Rodgers et al. (2015) on a survey of BIM adoption in the Australian construction industry to determine the status quo in SMEs. It was concluded that the level of awareness is low amongst SMEs; focus on BIM business values, BIM benefits evaluation and clients demand were highlighted as variables that can improve the status. Similarly, Hosseini et al. (2018c) adopted competitive dynamics perspective (CDP). An innovation diffusion model of SMEs was also developed by Hosseini et al. (2016), and it was found that the adoption rate is fast, and focus should be placed on the supply chain rather than the organization/project context. These studies were carried out in the Australian construction industry and the majority of the respondents were micro companies.

Ghaffarianhoseini et al. (2016) studied the BIM readiness and awareness of SMEs using a questionnaire survey and it was concluded that 75% of the SMEs are non-adopters; and a major challenge is the lack of awareness of right strategies for BIM adoption and implementation (Ghaffarianhoseini et al., 2016). A conceptual framework to assist in the analysis of risks and rewards was developed by Lam et al. (2017) followed by a web-based decision support system (DSS) for SMEs in the United Kingdom. However, the framework was validated with a larger percentage of larger firms than SMEs and risks were fixed. Gledson et al. (2012) in a qualitative study of large and SMEs in the United Kingdom discovered that there are significant differences in the opinions of SMEs and large firms as regards barriers to BIM in their organizations. The study of the digital divide gap between large and SMEs by Ayinla and Adamu (2018) via a questionnaire survey and in-depth interviews revealed that there are no differences in the sophistication of BIM technology engaged by these firms.

An empirical survey of SMEs revealed that there is an increase in the level of awareness and that BIM is a necessity in France (Tranchant et al., 2017). Similarly, Hochscheid et al. (2016) in a study carried out in a French architectural firm using case study method underscores the importance of considering the status quo for the organizations for BIM implementation. This was followed up by a review of key factors for success or failure of BIM in architectural firms (Hochscheid and Halinb, 2018).

Extant literatures on BIM focus mainly on large firms and a few research studies on SMEs were carried out in developed countries where the level of awareness in the construction industry is high as compared to developing countries. These studies were undertaken in countries with intense government support and clear directions for BIM execution. There is a scarcity of studies on BIM in developing countries and with focus on SMEs which are the backbone of economic development. Also, since the adoption of BIM is a complex decision, studying the interrelationships between the various factors affecting BIM adoption using system dynamics was adopted in this study.

2.1 Differences/Similarities in BIM Adoption between Small and Medium-sized Enterprises (SMEs) and Large Firms

Albeit, both large firms and the SMEs operate in the same construction industry, and they belong to different niches and operate separately. The difference in size lead to differences in organizational structure (Parida et al., 2010). They face different economic and social constraints (Ayinla and Adamu, 2018) and behaves differently for survival (Sexton et al., 2006). Thus, a singular view to this two different sides of the coin will not necessarily reflect the other side and it is unrealistic (Lu, 2005). In addition, extant studies have emphasized the importance of size in innovation/BIM adoption in firms (Sexton et al., 2006, Loveday et al., 2016, Construction, 2012, Eadie et al., 2013, Barata and Fontainha, 2017). Large firms are known to invest largely in research and development when compared to SMEs with low level of innovation capability and are always slow with innovation adoption because of their resources (Poirier et al., 2015). The SMEs are often unwilling to invest in innovation that are far away from their comfort zone because it requires huge investment and risks (Sexton et al., 2006). They are fast to adopt innovations which can contribute to the business in a short time and which can fit into existing organizational capabilities (Sexton et al., 2006). However, the BIM adoption is perceived to be a radical process (Udomdech et al., 2018), disruptive (Hochscheid et al., 2016), a major change (Arayici et al., 2009), and problematic (Hosseini et al., 2018c) by the SMEs.

Extant research studies have highlighted the differences/similarities in the perception of BIM by both the SMEs and large firms. Hong et al. (2019) concluded that all types of firms gives utmost consideration to 'technical support' in BIM adoption. Ayinla and Adamu (2018) corroborated that there is no clear difference between the two scales of firms as regards sophistication and application of BIM technology. Kori et al. (2019) opined that SMEs are unable to afford the initial investment cost of BIM implementation immediately as compared to large firms with 'organizational slack' which support risk-taking and experimentation with innovations (Abbott et al., 2007). Amuda-Yusuf (2018) added that large firms perceived cost to be moderate and involvement of other stakeholders to be critical in BIM adoption. Influence of variables such as government mandate is often considered to be influential on large firms that are often involved in public sector projects (Loveday et al., 2016). Thus, SMEs that seem to favor private sector projects which have no legal obligation or mandate to adopt BIM (Lam et al., 2017). Also, variables such as benefits (cost and time savings) and legal barriers are reported to be perceived differently by these two scales of firms (Gledson et al., 2012). Furry et al. (2017) concluded that a lack of expertise, high cost of implementation, and resistance to change are the major barriers hindering BIM adoption in SME firms in Indonesia, whereas Hosseini et al. (2016) revealed that they are no longer the challenges of BIM in the Australian SMEs but challenges encountered to be a lack of clear BIM benefits. Hong et al. (2019) asserted that 'operational risks' are of higher importance to the SMEs, while 'implementation challenges' are of much importance to large firms in the Chinese construction market. These extant findings emphasized that SMEs and large firms have some similarities but are also fundamentally different in nature (Sexton et al., 2006), and often react to variables differently. Also, BIM research studies on SMEs are contextual and specific, and they would vary from place to place as well.

3. Research Methodology

3.1 Identification of Barriers to and Benefits of BIM Adoption

Research articles on Building Information Modelling (BIM)'s challenges, barriers and benefits were searched using the search engine of SCOPUS, and the outputs were confined to English and construction-related articles. The confined articles were then refined to developing countries, as this is the region under investigation. Scopus was selected as it has a wider range of coverage (Hosseini et al., 2018a; Hosseini et al., 2018b). Figure 1 portrays the research design of the study. The research articles retrieved from Scopus were then critically reviewed and analyzed, and major barriers, challenges and benefits of BIM adoption were then captured, and similar challenges/benefits were merged. The challenges were viewed from two perspectives at organisation/project level and industry level; the barriers were then also grouped into technology-related barriers, economic-related barriers, and people/process-related barriers. The number of times of occurrence of the same or similar benefits/barriers mentioned was recorded in order to reveal their frequencies "freq" in the reviewed literatures.

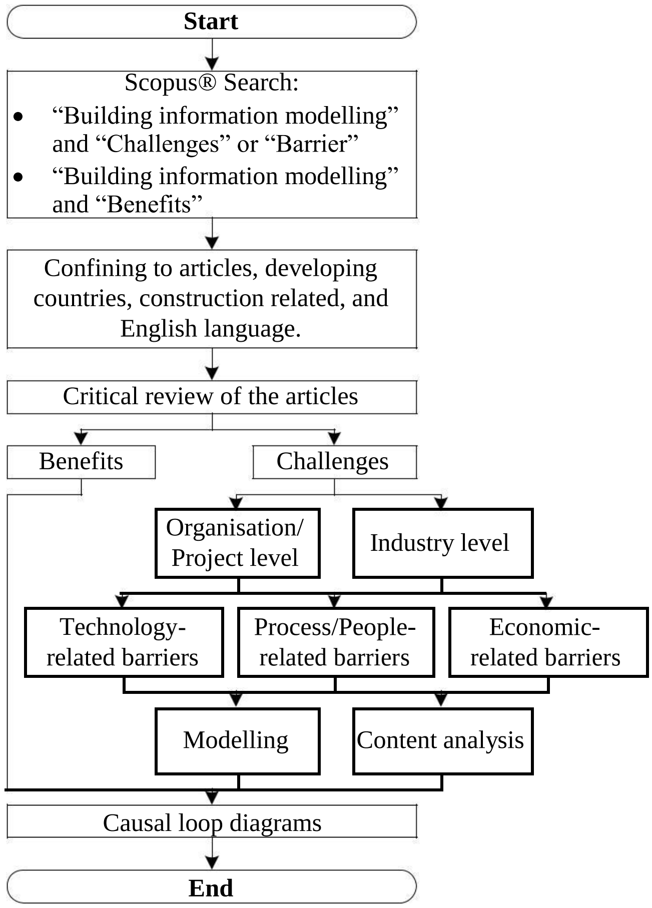

Figure 1: Outline of Research Design

3.2 System Dynamics (SD) Modelling

System dynamics (SD) approach was used to study the reasons for low BIM adoption rate in SMEs of developing countries. SD was invented by Professor Jay Forrester in the 1950s (Forrester, 1987). It is a mathematical modelling technique to help with policy/strategy formation and study cause-effect relationships of a problem. It involves multiple feedback loops and time delay which are often the cause of unexpected behaviours in the system. The SD modelling starts from problem structuring to causal loop modelling, through dynamic modelling, to scenario planning and modelling, and finally to implementation and organization learning (Mamter et al., 2017). It has been applied in the construction industry (Ogunlana et al., 1998) in the past. The focus of this study is to develop the causal loop diagrams which are beneficial for mapping the causal effects and feedbacks of the system. It gives a representation of the system using nodes, arrows and these form feedback loops of the system. A conceptual causal loop modelling was then developed using the software platform "Vensim PLE (version 7.3.5)" (Vensim, 2018).

The causal loop consists of nodes and arrows; and these form feedback loops. A loop can be either a reinforcing loop or a balancing loop depending on the number of negative signs in the loop. Even negative (-) signs give a reinforcing (R) loop and odd negative (-) signs give a balancing (B) loop. The reinforcing feedback loop change with more change and can lead to a rapid rate of increase (either positive or bad), thus it can either be accelerating or destabilizing the system. The balancing loop, on the other hand, is a stabilizing and compensating loop and often result in goal-seeking or oscillation growth. It is worthy of note that causal loop does not represent the behaviours of the system, and it is a conjecture that will be tested by developing the stock and flow diagram with equations which will, in turn, estimate the actual behaviours of the system. Figure 2 shows a simple causal loop with the respective reinforcing loop and balancing loop.

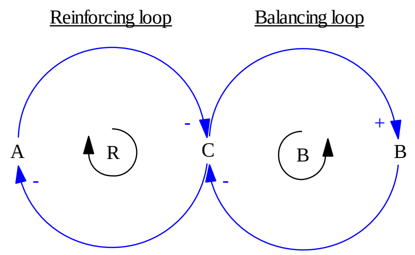

Figure 2: Causal Loop Diagram (CLD)

4. Results and Discussions

4.1 Barriers to BIM adoption

A desktop review of the articles reveals many barriers/challenges to the adoption of BIM in developing countries. These barriers were then grouped into three categories of technology-related barriers, economic-related barriers and people/process-related barriers; while using the perspective of organization/project and industry as shown in Table 1.

Technology-related barriers: Interoperability is one of the technology-related barriers that has been affecting the widespread adoption of BIM in the construction industry and it carries the highest occurrence in the literature reviewed. These technology-related-barriers are severe in developing countries that are still struggling with low information technology infrastructure (Abubakar et al., 2014). Thus, there is still the perception of the BIM technology being complex and not easy to use at the organization/project level which inevitably reflects in the low investment in BIM technology. Also, a clear understanding of BIM is still a major barrier, as some stakeholders still perceive BIM to be 3D modelling (Onungwa et al., 2017).

Economic-related barriers: The high cost of implementation and training of staff are the significant barriers to BIM adoption at the organization/project level. Most organisations have limited resources and investing in BIM where there is still a lack of conspicuous financial benefits from its adoption which is considered too risky. Thus, there is no motivation and mandate for its adoption both at the organization and industry levels which could have pushed some organisations to adopt BIM. The cost incurred for staff training on BIM was also posed as a major barrier in developing countries with few trained professionals (Abubakar *et al.*, 2014) and lack of educational curriculum support for producing BIM compliant graduates in the industry.

Process/People-related barriers: This is the most severe of the barriers, as BIM is a process of using technology; and it has been opined to be 10% technology and 90% process and people (Munir and Jeffrey, 2013). There is still resistance to change in the firms (Abubakar *et al.*, 2014;Ismail *et al.*, 2017) as a result of the perception that the current system is sufficient which inevitably leads to a lack of support from senior management. Also, because of the low level of awareness amongst the stakeholders, there is an unwillingness to share information and there is no demand for the use of BIM by the clients. Government policies and directions have a tremendous effect on the adoption of BIM which has been observed in developed countries, but this is not the case in most developing countries and thus there is no clear established standard for BIM implementation. There is an urgent need for proper orientation of the stakeholders for an effective BIM adoption in the industry, as they can make or mar its adoption.

Table 1: Barriers to BIM Adoption in Developing Countries

	Technology -	**Freq**	**Economic-related**	**Freq**	**Process/People -**	**Freq**

	related barriers	**(85)**	**barriers**	**(110)**	**related barriers**	**(207)**
Organization / Project level	Lack of ICT tools	12	High cost of staff training	27	Resistance to change	29
	Misunderstanding of BIM technology	12	Cost of BIM implementation	27	Lack of top management support	8
	BIM is complex in use	3	No clear financial benefits	12	Lack of in-house skilled professionals	23
	Lackof BIM technology investment	3	No incentive / motivation for adoption	3	Lack of awareness	20
					Unwillingness of partners	20
Industry level	Interoperability	19	Lack of education and training	23	Lack of collaborative procurement system	17
	Lack of information technology infrastructure	12	No mandate for adoption	3	No government policy/direction	15
	Poor internet connectivity	12	Lack of BIM benefits evaluation	12	Lack of demands from client	14
	Sufficient power supply	12	No risk insurance	3	Lack of skilled professionals in the industry	23
					Lack of information sharing between the stakeholders	
					Lack of standards	

Freq = Frequency of occurrence in the desktop literature reviewed.

4.2 Benefits of BIM adoption

During the literature review search, it was apparent that there are so many research studies on barriers of BIM adoption in developing countries than studies on benefits of its adoption. This can be attributed to the enormous barriers that needed to be overcome for adoption before reaping the benefits. However, it is also necessary to increase the level of awareness of stakeholders about the perceived benefits, as this may also help to increase adoption. One of the main barriers to BIM adoption in developing countries is the lack of awareness of the benefits and lack of empirical studies for these benefits. The benefits were not grouped into categories as done for the barriers/challenges, as there is no clear compartmentalization. The identified benefits are summarized in Table 2. Most of the reported benefits in developing countries are not based on empirical studies, but they are merely the perceived benefits from the stakeholders. It is not surprising to see improved visualization as one of the most reported benefits because most are still familiar with visualization functionalities of BIM. The perceived benefits can only be achieved with proper BIM adoption at the organization/project level and at the industry level.

Table 2: Benefits of BIM Adoption in Developing Countries

S/N	**Benefits**	**Freq**
1	Improved design quality/visualization	16

2	Faster design production	16
3	Improved productivity and efficiency	15
4	Better contract documentation	15
5	Better project coordination	15
6	Improved communications	15
7	Clash detection	15
8	Saving in time	14
9	Reduced design errors/rework	12
10	Reduced risk	12
11	Saving in cost	12
12	More collaboration between project stakeholders	12
13	Early integration of project stakeholders	12
14	Life cycle data management	11
15	Better cost estimating and accuracy	9
16	Data management and accuracy	7
17	Higher sustainability	7
18	Auto-quantity generation	6
19	Competitive edge	5
20	Positive return on investment	4

Freq = Frequency of occurrence in the desktop literature reviewed.

4.3 Causal Loop Diagrams (CLD)

Figure 3 illustrates the causal loop diagram at the organization/project level. Seven loops were identified with four reinforcing loops and three balancing loops

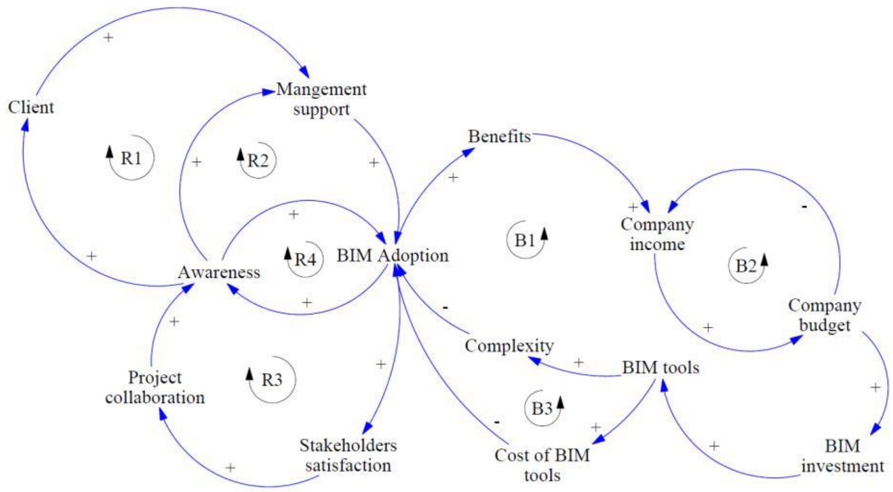

Figure 3: Conceptual causal loop for BIM adoption in SMEs of developing countries (Organization/Project level).

The following are the reinforcing loops in the causal loop diagram:

Reinforcing loop
R1: BIM adoption $^{+}\rightarrow$ Awareness $^{+}\rightarrow$ Clients $^{+}\rightarrow$ Management support $^{+}\rightarrow$ BIM adoption. This loop is the reinforcing adoption loop by the push by the clients, this is often lacking in developing countries where the clients lack adequate awareness about BIM. A proper awareness of BIM by the clients will lead to an increase in demand of BIM by the clients. This will force the management of the firms to adopt BIM on their projects and adoption, on the other hand, it will also increase their awareness.

R2: BIM adoption +→ Awareness +→ Management support +→ BIM adoption.
Lack of awareness of the management staff will lead to lack of support for the BIM adoption and increase their resistance to change and this is prominent in developing countries where there is a perception that the current traditional system is adequate. An increase or decrease in the level of awareness of the management staff will have an increasing or decreasing effect on the BIM adoption.

R3: BIM adoption +→ Stakeholders satisfaction +→ Project collaboration +→ Awareness BIM adoption.
Asides the clients, there are other stakeholders in the construction projects like the subcontractors and partnering firms. BIM adoption can lead to an increase or decrease in stakeholders' satisfaction and which will, in turn, affect project collaboration and awareness level.

R4: BIM adoption +→ Awareness +→ BIM adoption.
This another reinforcing loop that shows the relationship between awareness and BIM adoption. An increase or decrease in the level of awareness will have an increase or decreasing effect on the BIM adoption.

The following are the balancing loops in the causal loop diagram:

B1: BIM adoption +→ Benefits +→ Company Income +→ Company budget +→ BIM investment +→ BIM tools +→ Complexity −→BIM adoption.
This is a balancing loop of BIM adoption in the firm. An increase in BIM adoption can lead to an increase or decrease in the benefits attached to it. This will have the same effect on the company's income and will, in turn, determine the direction of the company's budget. An increase or decrease in the company's budget will have an effect on the BIM investment and which will inevitably determine the available BIM tools. The complexity of the BIM tools will also have an effect on the adoption, as one of the challenges of its adoption in developing countries is its complexity/ease of use.

B2: Company Income +→ Company budget −→ Company Income.
This is a balancing loop between the company's income and budget. An increase in the company's income will lead to a rise in a company's budget as there will be more resources. As the company's budget increases (expenses), it reduces the company's income and thus balancing the loop.

B3: BIM adoption +→ Benefits +→ Company Income +→ Company budget +→ BIM investment +→ BIM tools +→ Cost of BIM tools −→BIM adoption.
BIM adoption influences the benefits which in turn have effect on the company's income, budgets, investment, and BIM tools. The cost of the BIM tools in turn has an opposing effect on BIM adoption. An increase in cost will lead to a decrease in BIM adoption and vice versa. The cost of implementation has been said to be one of the major challenges towards SMEs in developing countries as these small and medium-sized firms have scare resources.

Figure 4 portrays the causal loop for the BIM adoption at the industry level and four loops were identified. All the four loops identified are reinforcing loops because they are all self-reinforcing and growth producing loops.

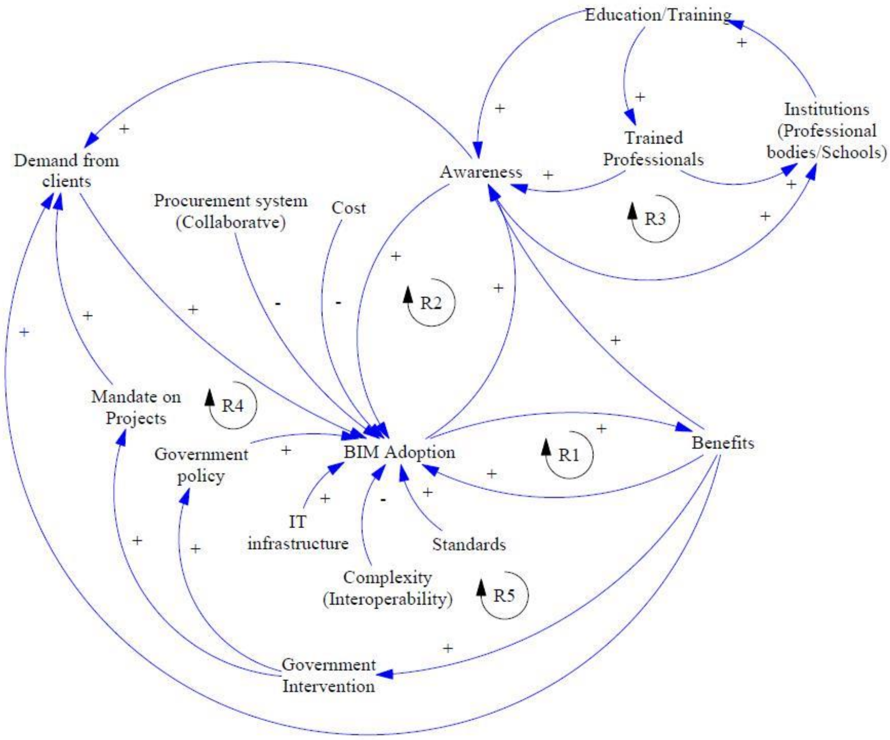

Figure 4: Conceptual causal loop for BIM adoption in SMEs of developing countries (Industry level).

The following are the reinforcing loops in the causal loop diagram:

R1: BIM adoption $\xrightarrow{+}$ Benefits $\xrightarrow{+}$ BIM adoption.
BIM adoption would lead to reaping of the benefits attached to its adoption and which will in turn lead to more BIM adoption in the industry. Therefore, clear benefits evaluation of BIM would lead to more BIM adoption in the industry.

R2: BIM Adoption $\xrightarrow{+}$ Awareness $\xrightarrow{+}$ BIM Adoption.
There is still low awareness about BIM in the construction industry of developing countries. Adopting BIM would lead to increase in awareness and which will in turn lead to more adoption.

R3: Awareness $\xrightarrow{+}$ Stakeholders $\xrightarrow{+}$ Education/Training $\xrightarrow{+}$ Awareness.
Awareness of the stakeholders in the industry would lead to provision of training/education.

R4: BIM Adoption $\xrightarrow{+}$ Benefits $\xrightarrow{+}$ Demand from clients $\xrightarrow{+}$ BIM Adoption.
The clients are also a driving force at the industry level. The benefits from BIM adoption would prompt the clients to demand for BIM.

R5: Government intervention $\xrightarrow{+}$ Government Policy $\xrightarrow{+}$ BIM adoption $\xrightarrow{+}$ Benefits Government Intervention.
The biggest driver of BIM is the government, as the government represents the biggest client of the industry in developing countries. Intervention of the government would lead to clear policy as seen in the developed nations. The policy would in turn lead to BIM adoption in the industry, more benefits of BIM adoption will lead to more government intervention as seen in the developed construction industry.

5. Conclusions

In the bid towards a smart construction industry, there is a great need for integration of the present fragmented construction industry. The BIM is a collaborative tool and process that can help with the integration of the industry towards the goal of smart industry. However, BIM that is meant to help with the integration is leading to further fragmentation of the industry along the line. There exists a 'digital divide' between 'BIM complaint' SMEs and 'BIM compliant' large firms. The current study revealed that there is a dearth of research studies on building information modelling (BIM) adoption in SMEs and the few extant studies were carried out in developed countries where the level of awareness is higher, technology infrastructure is higher and more government support/directions as against developing countries where there is still a lack of standards for BIM implementation in the construction industry. Various challenges are plaguing developing countries as regards BIM adoption. The high cost of staff training, and cost of BIM implementation appear to be the frequent challenges identified in the literature which have hindered the adoption of BIM. There is still a high level of resistance amongst the professionals to change, as there is a perception that the current traditional system is sufficient, and this can be attributed to their lack of clear understanding about BIM. These factors also inevitably lead to a lack of trained professionals at both the industry level and organization level. The process/people-related challenges are the most frequent challenges, as BIM is more related to people than technology. There is also a scarcity of research studies on BIM benefits evaluation in developing countries that are still struggling with its adoption. Empirical research studies on BIM benefits evaluation will increase awareness and encourage various project stakeholders, especially clients and the government to align towards the goal of a smart construction industry. The two conceptual causal models have presented the cause-effect relationships of the BIM adoption behaviours in the SMEs of developing countries at the organization/project level and at the industry level, respectively. The awareness, management support, benefits and investment cost of BIM are important variables that can make or mar BIM adoption at the organization/project level while awareness, institutions, benefits and the government are the significant variables that can make or mar BIM adoption at the industry level. It should be stressed that the causal loop does not present the exact directions rather it only elicits the variables which will lead to empirical system dynamics modelling and stocks and feedback loops; and the results from the SD modelling will provide better adoption policies for the organisations and the behaviours of the system will be made more detailed and clearer for execution in practice.

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References

Abubakar, M., Ibrahim, Y.M., Kado, D. and Bala, K., 2014. Contractors' perception of the factors affecting Building Information Modelling (BIM) adoption in the Nigerian Construction Industry. *Computing in Civil and Building Engineering* (pp. 167-178). doi: 10.1061/9780784413616.053.

Abbott , C., Sexton, M., Jones, V. & Lu, S.-L. 2007. Action learning as an enabler for successful technology transfer with construction SMEs. RICS Research paper series.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'reilly, K., 2011. Technology adoption in the BIM implementation for lean architectural practice. *Automation in Construction*, *20*(2), pp.189-195. doi: 10.1016/j.autcon.2010.09.016.

Ayinla, K.O. and Adamu, Z., 2018. Bridging the digital divide gap in BIM technology adoption. *Engineering, Construction and Architectural Management*, *25*(10), pp.1398-1416. doi: 10.1108/ECAM-05-2017-0091.

Barata, J. M. & Fontainha, E. 2017. Determinants of Innovation in European Construction Firms. *Technological and Economic Development of Economy*, 23, 915-936.

Construction, M.H., 2015. The Business Value of BIM For Construction in Major Global Markets: how contractors around the world are driving innovation with building information modeling. *Smart Market Report*.

Construction, M. H. 2012. McGraw-Hill Construction The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings. 72.

Eadie, R., Browne, M., Odeyinka, H., Mckeown, C. & Mcniff, S. 2013. BIM implementation throughout the UK construction project lifecycle: An analysis. *Automation in Construction*, 36, 145-151.

Egan, J., 1998. Rethinking construction: report of the construction task force on the scope for improving the quality and efficiency of UK construction. *Department of the Environment, Transport and the Regions, London*.

Forrester, J.W., 1987. Lessons from system dynamics modeling. *System Dynamics Review*, *3*(2), pp.136-149.

Furry, A. W., Dewi, L. & Suhendri, S. 2017. The Challenges of Implementing Building Information Modeling in Small-Medium Enterprises Architecture Firms in Indonesia. *19th International Conference of Architecture, Interior Design, and Construction Management.*

Gledson, B., Henry, D. & Bleanch, P. 2012. Does size matter? Experiences and perspectives of BIM implementation from large and SME construction contractors. *1st UK Academic Conference on Building Information Management (BIM)* 2012, 97-108.

Gbadamosi, A. (2018). Understanding the Developed/Developing Country Taxonomy | A4ID. [online] A4id.org. Available at: http://www.a4id.org/policy/understanding-the-developeddeveloping-country-taxonomy [Accessed 26 November 2018].

Ghaffarianhoseini, A., Doan, D.T., Zhang, T., Ghaffarianhoseini, A., Naismith, N. and Tookey, J., 2016. A BIM Readiness & Implementation Strategy for SME Construction Companies in the UK. In *Proceedings of the 33rd CIB W78 Conference*.

Gledson, B., Henry, D. and Bleanch, P., 2012. Does size matter? Experiences and perspectives of BIM implementation from large and SME construction contractors. *1st UK Academic Conference on Building Information Management (BIM) 2012*, (September), pp. 97–108. doi: 10.13140/RG.2.1.5168.7280.

Harris, R., McAdam, R., McCausland, I. and Reid, R., 2013. Levels of innovation within SMEs in peripheral regions: the role of business improvement initiatives. *Journal of Small Business and Enterprise Development*, *20*(1), pp.102-124.doi: 10.1108/14626001311298439.

Hochscheid, E., Ribereau-Gayon, M., Halin, G. and Hanser, D., 2016, July. BIM Implementation in SMEs: an Experience of Cooperation between an Architect Agency and a Carpentry Firm. In *International Conference on Computing in Civil and Building Engineering* (pp. 6-8). doi: 10.1115/DETC2005-84065.

Hochscheida, E. and Halinb, G., 2018. 'A model to approach BIM adoption process and possible BIM implementation failures'. In *Proceedings of the Creative Construction Conference (CCC) 2018*.

Hosseini, M., Banihashemi, S., Chileshe, N., Namzadi, M.O., Udaeja, C., Rameezdeen, R. and McCuen, T., 2016. BIM adoption within Australian Small and Medium-sized Enterprises (SMEs): an innovation diffusion model. *Construction Economics and Building*, *16*(3), p.71. doi: 10.5130/AJCEB.v16i3.5159.

Hosseini, M.R., Maghrebi, M., Akbarnezhad, A., Martek, I. and Arashpour, M., 2018a. Analysis of citation networks in building information modeling research. *Journal of Construction Engineering and Management*, *144*(8), p.04018064. doi: 10.1061/(ASCE)CO.1943-7862.0001492.

Hosseini, M.R., Martek, I., Zavadskas, E.K., Aibinu, A.A., Arashpour, M. and Chileshe, N., 2018b. Critical evaluation of off-site construction research: A scientometric analysis. *Automation in Construction*, *87*, pp.235-247. doi: 10.1016/j.autcon.2017.12.002.

Hosseini, M.R., Pärn, E.A., Edwards, D.J., Papadonikolaki, E. and Oraee, M., 2018c. Roadmap to Mature BIM Use in Australian SMEs: Competitive Dynamics Perspective. *Journal of Management in Engineering*, *34*(5), p.05018008.

Hong, Y., Hammad, A. W. A. & Akbarnezhad, A. 2019. Impact of organization size and project type on BIM adoption in the Chinese construction market. *Construction Management and Economics*, 1-17.

Jung, W. and Lee, G., 2015. The status of BIM adoption on six continents. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, *9*(5), pp.444-448.

Kori, S. A., Itanola, M. & Saka, A. B. 2019. The Capability and Support of Structure Capital on BIM Innovation in SME. *Information and Knowledge Management*, 9, 56-66.

Lam, T.T., Mahdjoubi, L. and Mason, J., 2015. A web-based Decision Support System (DSS) to assist Small and Medium-sized Enterprises (SMEs) to broker risks and rewards for BIM adoption. *Building Information Modelling (BIM) in Design, Construction and Operations*, *149*, p.463. doi: 10.2495/BIM150381.

Lam, T.T., Mahdjoubi, L. and Mason, J., 2017. A framework to assist in the analysis of risks and rewards of adopting BIM for SMEs in the UK. *Journal of Civil Engineering and Management*, *23*(6), pp.740-752. doi: 10.3846/13923730.2017.1281840.

Love, P.E. and Irani, Z., 2004. An exploratory study of information technology evaluation and benefits management practices of SMEs in the construction industry. *Information & Management*, *42*(1), pp.227-242. doi: 10.1016/j.im.2003.12.011.

Loveday, J., Kouider, T. & Scott, J. 2016. The Big BIM battle. *Conference Proceedings of the 6Th International Congress of Architectural Technology*, 53-66.

Munir & Jeffrey, H., M. (2013) 'Building Information Modelling (BIM): A Summary of UK Experiences as Guide to Adoption in Nigeria', *Nigerian Institute of Quantity Surveyors: First Annual Research Conference*, (August).

Mamter, S., Aziz, A.R.A. and Zulkepli, J., 2017, November. Root causes occurrence of low BIM adoption in Malaysia: System dynamics modelling approach. In *AIP Conference Proceedings* (Vol. 1903, No. 1, p. 080011). AIP Publishing. doi: 10.1063/1.5011599.

NBS, 2017. NBS Nationl BIM Report 2017.

Ogunlana, S., Lim, J. and Saeed, K., 1998. Desman: A dynamic model for managing civil engineering design projects. *Computers & Structures*, *67*(5), pp.401-419. doi: 10.1016/S0045-7949(97)00148-X.

Olugboyega, O. 2018. Analysis of Building Information Modelling Usage Indices and Facilitators in the Nigerian Construction Industry. *Journal of Logistics, Informatics and Service Sciences*, *3(2)*, pp.1-36.

Onungwa, I.O., Uduma-olugu, N.N.E.Z.I. and Igwe, J.M., 2017. Building information modelling as a construction management tool in Nigeria. *WIT Transactions on The Built Environment*, *169*, pp.25-33. doi: 10.2495/BIM170031.

Poirier, E., Staub-French, S. & Forgues, D. 2015. Embedded contexts of innovation: BIM adoption and implementation for a specialty contracting SME. *Construction Innovation*, 15, 42-65.

Rodgers, C., Hosseini, M.R., Chileshe, N. and Rameezdeen, R., 2015. Building information modelling (BIM) within the Australian construction related small and medium sized enterprises: Awareness, practices and drivers. In *ARCOM 2015: Proceedings of the 31st Annual Conference of the Association of Researchers in Construction Management* (pp. 691-700). ARCOM. doi: 10.13140/RG.2.1.4790.7686.

Sexton, M., and, P. B. & Aouad, G. 2006. Motivating small construction companies to adopt new technology. *Building Research & Information,* 34, 11-22.

Tranchant, A., Beladjine, D. and Beddiar, K., 2017, BIM in french smes: From innovation to necessity, *WIT Transactions on the Built Environment*, 169, pp. 135–142. doi: 10.2495/BIM170131.

Udomdech, P., Papadonikolaki, E. & Davies, A. An Alternative Project Based Learning Model for Building Information Modelling-Using Teams. Proceeding of the 34th Annual ARCOM Conference, ARCOM 2018, 2018. 57-66.

United Nations 2001. Improving the Competitiveness of SMEs in Developing Countries: the Role of Finance, Including E-finance, to Enhance Enterprise Development. *UNITED NATIONS CONFERENCE ON TRADE AND DEVELOPMENT.*

Vensim. (2018). *Vensim Help*. [online] Available at: https://www.vensim.com/documentation/index.html?users_guide.htm [Accessed 3 Nov. 2018].

Wong, A.K.D., Wong, F.K.W. and Nadeem, A., 2011. Government roles in implementing building information modelling systems: Comparison between Hong Kong and the United States. *Construction Innovation*, *11*(1), pp.61-76. doi: 10.1108/14714171111104637.